

## Effects of Forest Gap Size on Mass Loss and Nutrient Release of Four Litter Types in *Pinus massoniana* Plantations (Postprint)

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### Abstract

Decomposition of plant litter in the tree layer of Masson pine (*Pinus massoniana*) plantations plays a vital role in forest nutrient balance and ecosystem material cycling, and may be influenced by microenvironmental variations under different-sized forest gaps. Using the litterbag decomposition method, this study investigated seven artificially created gaps of varying sizes (G1: 100 m<sup>2</sup>, G2: 225 m<sup>2</sup>, G3: 400 m<sup>2</sup>, G4: 625 m<sup>2</sup>, G5: 900 m<sup>2</sup>, G6: 1225 m<sup>2</sup>, G7: 1600 m<sup>2</sup>) in a Masson pine plantation, with under-canopy (G0) as the control, to examine the effects of gap size on leaf litter mass loss and nutrient release of four native tree species: *Toona ciliata*, *Phoebe zhennan*, *Cinnamomum camphora*, and *Pinus massoniana*. The results showed: 1) Gap size (G0–G7) significantly affected N and P release rates of *T. ciliata* and *P. zhennan* leaf litter placed at gap centers, mass loss rate and N, P, K release rates of *C. camphora* leaf litter, and P and K release rates of *P. massoniana* leaf litter. Compared with under-canopy, small- to medium-sized gaps (G1–G4) exhibited significantly higher mass loss rates and N and P release rates, whereas large gaps (G6–G7) showed significantly higher K release rates. 2) Placement position within gaps significantly influenced K release rates of *T. ciliata*, *P. zhennan*, and *P. massoniana* leaf litter, and P release rate of *C. camphora* leaf litter. K release rates of *T. ciliata* and *P. zhennan* leaf litter decreased significantly from gap center to edge, while K release rate of *P. massoniana* leaf litter and P release rate of *C. camphora* leaf litter increased significantly from gap center to edge. 3) Among the four litter types, *T. ciliata* leaf litter decomposed the fastest, requiring 5.29 and 23.14 months for 50% and 95% decomposition, respectively. These results demonstrate that both gap size and within-gap position significantly affect litter mass loss and nutrient release, but the magnitude and trend of these effects vary markedly with differences in initial substrate quality among species. The findings provide a scientific basis for

scientific management of low-efficiency Masson pine plantations in subtropical low mountain and hilly regions.

## Full Text

### Preamble

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### Effects of Forest Gap Size on Leaf Litter Weight Loss and Nutrient Release of Four Species in *Pinus massoniana* Plantations

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### Effects of Forest Gap Size on Leaf Litter Weight Loss and Nutrient Release of Four Species in *Pinus massoniana* Plantations

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## Abstract

Leaf litter decomposition in the arbor layer of *Pinus massoniana* plantations is crucial for maintaining forest floor nutrient balance and ecosystem material cycling, and may be influenced by microenvironmental variations associated with different gap sizes. Using the litterbag decomposition method, we examined the effects of gap size on leaf litter mass loss and nutrient release for four native species: *Toona ciliata*, *Phoebe zhennan*, *Cinnamomum camphora*, and *Pinus massoniana*. Seven gap sizes were established in 2013 through selective harvesting: G1 (100 m<sup>2</sup>), G2 (225 m<sup>2</sup>), G3 (400 m<sup>2</sup>), G4 (625 m<sup>2</sup>), G5 (900 m<sup>2</sup>), G6 (1225 m<sup>2</sup>), and G7 (1600 m<sup>2</sup>), with intact forest understory (G0) as control. Gap size significantly affected the mass loss of *T. ciliata* and *P. zhennan* leaf litter placed at gap centers, as well as nutrient (N, P, K) release rates for *C. camphora* and *P. massoniana*. Compared with understory conditions, small and medium gaps (G1-G4) showed significantly higher mass loss rates and N and P release rates, but lower K release rates, than large gaps (G5-G7). Litter placement position within gaps significantly influenced K release rates for *T. ciliata*, *P. zhennan*, and *P. massoniana*, and N and P release rates for *C. camphora*. For *T. ciliata* and *P. zhennan*, N and P release rates decreased significantly from gap center to edge, whereas K release rates for *C. camphora* and *P. massoniana* increased significantly from center to edge. Among the four litter types,

*T. ciliata* decomposed fastest, with 50% and 95% decomposition times of 5.29 and 23.14 months, respectively. These results demonstrate that both gap size and within-gap position significantly affect litter mass loss and nutrient release, though the magnitude and direction of these effects vary with species-specific initial litter quality. The findings provide scientific guidance for the ecological management of low-efficiency *P. massoniana* plantations in subtropical low mountain and hilly regions.

**Keywords:** forest gap size; *Pinus massoniana* plantation; mass loss rate; nutrient leaching; leaf litter traits

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## 1. Study Area Overview

The study was conducted in Gaoxian County, Yibin City, Sichuan Province (28°40'21"–28°42'44" N, 104°35'00"–104°39'13" E). The region has a subtropical humid monsoon climate with distinct three-dimensional climate patterns, mean annual temperature of 18.1°C, and annual precipitation of 1021.8 mm. The experimental site was located in a *Pinus massoniana* plantation along the Chuan-Yun Central Road at Maodian' ao. Soils are mountainous yellow soil. The plantation has simple stand structure, with *P. massoniana* as the dominant tree species at a spacing of 2.5 m × 2.5 m. Understory vegetation coverage is approximately 0.7–0.8, with major shrubs including *Mallotus japonicus*, *Rubus pyrifolius*, and *Myrsine africana*, and major herbs including *Phytolacca acinosa*, *Dicranopteris dichotoma*, *Miscanthus sinensis*, *Pteridium aquilinum*, and *Setaria plicata*.

In October 2013, we selected 45-year-old *P. massoniana* plantations with similar site conditions (terrain, slope position, etc.) and stand densities. Seven near-square gaps of varying sizes were created through harvesting: G1 (100 m<sup>2</sup>), G2 (225 m<sup>2</sup>), G3 (400 m<sup>2</sup>), G4 (625 m<sup>2</sup>), G5 (900 m<sup>2</sup>), G6 (1225 m<sup>2</sup>), and G7 (1600 m<sup>2</sup>). These were classified as small (G1–G2), medium (G3–G4), and large gaps (G5–G7). An intact *P. massoniana* stand (>1600 m<sup>2</sup>) served as the control (G0). Each treatment had three replicate plots. Basic plot characteristics are provided in Supplementary Table S1.

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## 2. Materials and Methods

### 2.1 Plot Design and Litterbag Deployment

Fresh leaf litter of *P. massoniana*, *T. ciliata*, *P. zhenan*, and *C. camphora* was collected from the plantation in late October 2013. After air-drying, 10 g samples were weighed and placed in 20 cm × 20 cm litterbags with 0.5 mm mesh. To account for potential mass loss during installation, initial moisture

content was determined by oven-drying subsamples to constant weight at 65°C, followed by grinding for initial substrate quality analysis.

Litterbags were deployed in November 2013 along a transect from gap center to forest understory on a uniform slope aspect. Gap center was defined as the geometric center of the canopy opening; gap edge was defined as the area bounded by the canopy gap edge and the bases of surrounding border trees. At each position (gap center, gap edge, and understory), litterbags were placed flat on the soil surface. Button temperature-humidity loggers were installed in litterbags at gap centers and understory positions, recording data every 2 hours. Litterbags were retrieved after 3, 6, 9, and 12 months. Upon retrieval, attached soil particles were removed, and samples were oven-dried to constant weight at 65°C and weighed.

## 2.2 Sample Analysis

Total carbon was determined by the potassium dichromate heating method (GB 7657-87). Total nitrogen was measured by the Kjeldahl method after digestion with H<sub>2</sub>SO<sub>4</sub>-H<sub>2</sub>O. Total phosphorus was determined by molybdenum-antimony colorimetry, and total potassium by flame photometry. Lignin content was measured using the Van Soest method (LY/T 1269-1999, LY/T 1270-1999): 0.5 g of dried, ground plant material was placed in a 170-175°C wax bath for 5 minutes, then extracted with acetone until transparent.

## 2.3 Calculation Formulas

Litter weight loss rate was calculated as:

$$D_{wi} = \Delta W / W$$

where  $D_{wi}$  is the weight loss rate,  $\Delta W$  is the weight loss at each sampling time (g), and  $W$  is the initial weight (g).

Nutrient release rate was calculated as:

$$E_i = (e_0 - e_i) / e_0 \times 100\%$$

where  $E_i$  is the net nutrient release rate at month  $i$  (%),  $e_0$  is the initial nutrient content (g), and  $e_i$  is the residual nutrient content at month  $i$  (g).

The Olson exponential decay model was used:

$$y = ae^{-kt}$$

where  $y$  is the litter residual rate (%),  $k$  is the decomposition coefficient,  $t$  is time,  $a$  is a fitted parameter, and  $e$  is the natural logarithm base.

## 2.4 Data Analysis

Statistical analysis was performed using SPSS 20.0, with graphs prepared using Excel 2007 and SigmaPlot 12.5. Three-way ANOVA was used to analyze the effects of gap size, position, and species on weight loss and nutrient release rates, followed by LSD tests for multiple comparisons. One-way ANOVA was used to analyze differences in weight loss and nutrient release rates among gap sizes for each litter type. Independent samples t-tests compared center vs. edge positions. Significance level was set at  $P < 0.05$ .

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## 3. Results

### 3.1 Initial Nutrient Content of Leaf Litter

Initial C, N, P, K, C/N, C/P, and lignin contents differed significantly among species (Table 1). Carbon content ranked: *T. ciliata* > *C. camphora* > *P. zhennan* > *P. massoniana*. Nitrogen and phosphorus contents ranked: *T. ciliata* > *P. zhennan* > *C. camphora* > *P. massoniana*. Potassium content ranked: *P. massoniana* > *P. zhennan* > *C. camphora* > *T. ciliata*. Lignin content ranked: *P. zhennan* > *P. massoniana* > *C. camphora* > *T. ciliata*.

### 3.2 Weight Loss Rates Across Gap Sizes

Three-way ANOVA showed that gap size significantly affected weight loss rate, with significant interactions with position and species. Gap size significantly influenced weight loss of *C. camphora* at gap centers and *T. ciliata* and *P. zhennan* at gap edges. Compared with understory (G0), weight loss rates were significantly higher in G1-G5 for *T. ciliata*, G1-G4 for *P. zhennan*, and G1-G7 for *C. camphora* and *P. massoniana* (Figure 1). Small and medium gaps (G1-G4) showed the highest weight loss rates.

[Figure 1: see original paper]

### 3.3 Nutrient Release Rates Across Gap Sizes

Gap size significantly affected nutrient release rates, with significant interactions with position and species. Gap size significantly influenced N and P release from *T. ciliata* and *P. zhennan* at gap centers, and N, P, K release from *C. camphora* and *P. massoniana* at gap edges. Compared with understory, small and medium gaps (G1-G4) showed significantly higher N and P release rates but lower K release rates than large gaps (G5-G7). Among species, *T. ciliata* showed the highest N, P, and K release rates, while *P. massoniana* showed the lowest (Figure 2).

[Figure 2: see original paper]

### 3.4 Effects of Position Within Gaps

Position within gaps had no significant main effect on weight loss or nutrient release but showed significant interactions with species. Weight loss rates did not differ significantly from gap center to edge for any species. However, N and P release rates for *T. ciliata* and *P. zhennan* decreased significantly from center to edge, while K release rates for *C. camphora* and *P. massoniana* increased significantly from center to edge (Table 3).

### 3.5 Decomposition Rates Among Species

*Toona ciliata* showed the highest weight loss and nutrient release rates among the four species. The Olson exponential model indicated that *T. ciliata* had the fastest decomposition rate ( $k = 0.129$ ), with 50% and 95% decomposition times of 5.29 and 23.14 months, respectively. *Cinnamomum camphora* had intermediate rates ( $k = 0.051$ ; 15.47 and 70.02 months), while *Pinus massoniana* decomposed slowest ( $k = 0.043$ ; 13.16 and 58.31 months) (Table 4).

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## 4. Discussion

### 4.1 Effects of Gap Size on Leaf Litter Decomposition and Nutrient Release

Gap formation alters understory light conditions, temperature, and humidity, creating microenvironmental differences among gap sizes that affect litter decomposition. Small and medium gaps (G1-G4) maintain higher humidity and more stable conditions, promoting soil fauna and microbial activity, especially during initial gap formation when herbaceous vegetation is abundant. In contrast, large gaps (G5-G7) experience more dramatic environmental fluctuations and greater spatial heterogeneity, which can slow decomposition. The understory (G0) shows reduced decomposition rates due to shading by canopy trees.

Gap size effects varied by species. The minimal response of *P. zhennan* may be attributed to its thick, tough leaves that are less sensitive to environmental changes. In contrast, *T. ciliata* showed strong responses due to its soft leaves that react to even minor microenvironmental differences. Nutrient release patterns also differed: N and P release, primarily controlled by microbial decomposition, was enhanced in small-medium gaps where decomposition rates were higher. K release, dominated by leaching, was greater in large gaps where higher precipitation and light intensity enhanced physical fragmentation and leaching processes.

#### 4.2 Effects of Position on Leaf Litter Decomposition and Nutrient Release

Position within gaps significantly affected litter mass loss and nutrient release at gap edges, with small-medium gaps showing stronger edge effects than large gaps. This edge effect arises from unique environmental gradients and species interactions at the boundary between gap and forest. Studies show edge effect intensity decreases with gap age and size; our experiment, conducted during initial gap formation, detected stronger edge effects in small-medium gaps where species diversity is lower.

Within-gap heterogeneity in temperature, humidity, and light creates distinct microenvironments. Gap edges have lower humidity and light due to canopy shading, slowing decomposition compared to centers. However, the contrasting patterns—where *T. ciliata* and *P. zhennan* showed higher N and P release at centers while *C. camphora* and *P. massoniana* showed higher K release at edges—reflect species-specific responses to microenvironmental gradients. These differences are closely related to initial litter quality, with water-soluble nutrients (K) responding more to leaching conditions at edges, while organic-bound nutrients (N, P) respond more to decomposition processes enhanced at centers.

#### 4.3 Effects of Tree Species on Leaf Litter Decomposition and Nutrient Release

Initial litter quality is a primary determinant of decomposition rate. Key indicators include C/N ratio and lignin content; higher lignin content slows decomposition. *Toona ciliata* decomposed fastest due to its lowest C/N ratio and lignin content, while *P. massoniana* was slowest due to high lignin content. *Phoebe zhennan*, despite high initial nutrient content, had moderate decomposition rates because its thick cuticle and hard texture reduced water permeability and microbial accessibility.

The highest nutrient release rates in *T. ciliata* reflect its high initial nutrient concentrations, which support microbial activity. The significant effects of gap size and position on the four litter types demonstrate that microenvironmental changes alter decomposition processes, but the magnitude and direction depend on species-specific litter traits. Small-medium gaps (G1-G4) generally favor both mass loss and nutrient release, making them optimal for managing low-efficiency *P. massoniana* plantations. Introducing *T. ciliata* in these gaps could accelerate nutrient cycling and improve soil conditions, enhancing ecosystem stability.

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## Supplementary Material

**Supplementary Figure S1.** Map of sampling plots in the study region in Yibin City, Sichuan Province. G1-G7 represent gaps of 100, 225, 400, 625, 900, 1225, and 1600 m<sup>2</sup>; CK (G0) indicates understory control.

**Supplementary Table S1.** General characteristics of sampling plots in different sized forest gaps of *Pinus massoniana* plantations.

**Supplementary Figure S2.** Daily average temperature dynamics of sampling plots in the study region in Yibin City, Sichuan Province. G1-G7 represent gaps of 100, 225, 400, 625, 900, 1225, and 1600 m<sup>2</sup>; CK: understory; GC: gap center; GE: gap edge.

**Supplementary Table S2.** Daily average temperature during different decomposition stages for each gap size.

*Note: Figure translations are in progress. See original paper for figures.*

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